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# EVALUATION OF THE CHEMICAL COMPOSITION AND NUTRITIONAL QUALITY OF DEHULLED LUPIN SEED MEAL (*Lupinus* spp. L.) AND ITS USE FOR MONOGASTRICS ANIMAL NUTRITION: A REVIEW

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***Abstract***

*The utilization of the lupine seeds (Lupinus spp. L.) from low-alkaloids varieties in monogastric animals feeds is limited due to the presence of antinutritive factors. Studies show that a considerable improvement of the nutritional composition of lupine is achieved by dehulling the seeds. The seed dehulling process increases the crude protein and fat levels, and decreases the content of cellulose, neutral detergent fibers and acid detergent fibers. An improvement of the biological value of lupine protein and the nutritional quality of fat is also obtained by dehulling. Antinutritive factors, such as non-starch polysaccharides and oligosaccharides, are partially reduced by dehulling, because of their storage in high concentrations in the kernel. For poultry and swine feeding, the utilization of whole lupine seeds is limited due to the lack of endogenous enzymes for processing the antinutritional factors. Therefore, numerous studies highlight that the use of dehulled seeds realizes similar bioproductive performances as soybean by-products. This is possible if the optimal inclusion level of lupine in diets and the adequate balance in limited amino acids are realized. Lupine seeds are therefore a valuable alternative source of proteins and fat, which is proven to be able to support productions, while improving the quality of animal products.*

***Key words***: *dehulled, lupine seeds, monogastric animals, protein.*

## INTRODUCTION

Currently, concurrency for protein feed between humans and animals, especially monogastrics, determines protein sources to become progressively more limited and expensive (Henchion et al., 2017). The use of soybean seeds as the main plant protein source raises some ethical, ecological and especially economic issues, so it is necessary to find new possibilities to reduce dependence on the imported protein sources in Europe, while guaranteeing the security of origin (Kasprowicz et al., 2016). Lupine (*Lupinus* spp. L.) is considered a valuable vegetal protein source because of its nutritional profile comparable to other vegetal protein sources used in farm animalnutrition, such as soybean meal (De Visser et al., 2014). Lupin is part of the Fabaceae family, and the genus *Lupinus* includes 267 annual and perennial herbaceous species cultivated in different pedo-climatic areas (Drummond, 2008; Drummond et al., 2012).

The most commonly used species of sweet lupine are *Lupinus albus*, *Lupinus luteus* in Europe, *Lupinus angustifolius* in Australia and *Lupinus mutabilis* in South America (Lucas et al., 2015; Sedláková et al., 2016). Lupine has been shown to be successfully used in animal nutrition, thus becoming an integrated part of modern agriculture, also used to increase soil fertility due to nitrogen fixation, being considered a very good precursor plant for other crops (Seymour et al., 2012; Weisskopf et al., 2008). Presently, the use of lupins from low alkaloid varieties, so called sweet lupins, in the nutrition of monogastrics animals is limited due to their content in certain anti-nutritional factors, such as non-starch polysaccharides, oligosaccharides, hemicellulose, cellulose and especially neutral detergent fibers (NDF) and

acid detergent fibers (ADF) that are lowly digestible and reduce the digestibility of nutrients (Olkowski, 2010).
Studies show that the utilization of mechanical removal procedures of hulls from lupine seeds (such as dehulling) contributes to the increase in nutritional value and the degree of feed utilization and implicitly, to the bioproductive performances of the animals (De Vries et al., 2012). Therefore, the aim of this review is to highlight the effect of dehulling lupine seeds on the chemical composition and nutrition value of seeds and its use for monogastric animal nutrition.

## MATERIALS AND METHODS

## NUTRITIONAL CARACTERIZATION OF LUPINE SEEDS

Current researches about the chemical composition and nutritional quality of lupine seeds show a variable nutritional profile depending on the cultivars, pedoclimatic conditions and applied agrotechnics (Mierlita et al., 2012; Księżak et al., 2018; Tomczak et al., 2018).
In order to improve the nutritional value of lupine seeds, studies show that some procedures may be applied, such as dehulling, crushing, germination (Chilomer et al., 2013), decreasing particle size (Kim et al., 2009) roasting, microwaves, autoclaving (Batterham et al., 1986) and addition of specific enzymes. Among the physical methods, dehulling of seeds and use the kernel has proven to be an effective and economical method that considerably improves the nutritional value of lupine seeds (Embaby, 2010; Laudadio and Tufarelli, 2011a).

### *Chemical composition of lupine seed*

Numerous studies are focused on the chemical composition of whole lupine seeds characterized by high content in crude protein, crude fat and cellulose (Yilmaz et al., 2015; Bartkiene et al., 2016). Values differ according to lupine species, cultivars and pedoclimatic conditions, but are comparable to other vegetal protein sources, e.g. soybean (*Glycine max*) (Bähr et al., 2014) or faba bean (*Vicia faba*) (Mattila et al., 2018). Other studies have also shown that dehulling of lupine seeds determines a significant increase in protein and fat content, as well as a reduction in crude cellulose level, especially in cell wall constituents (NDF, ADF) and carbohydrates (Glencross et al., 2007; Večerek et al., 2008).
According to table 1, whole lupine seeds are characterized by variable protein content, between 25.01 and 42.8% in DM (dry matter). After dehulling the seeds, an increase in the level of crude protein is observed, having values between 31.1 and 54.4% in DM. Bähr et al (2014) mentions that the protein level in dehulled lupine seeds (from three species) is similar to the soybean protein level.

Table 1. Effect of dehulling on the chemical composition (% of dry matter) of low-alkaloid lupine seeds varieties

| Nutrients | *L. albus* | | | | *L. luteus* | | *L. angustifolius* | |
|---|---|---|---|---|---|---|---|---|
| | 1 | | 2 | | 3 | | 4 | |
| | WS | DS | WS | DS | WS | DS | WS | DS |
| Dry matter | 92.9 | 93.1 | 95.9 | 95.7 | - | - | 91.1 | 91.1 |
| Crude protein | 35.5 | 42.9 | 38.4 | 43.5 | 42.8 | 54.4 | 29.0 | 37.2 |
| Crude ash | 3.5 | 3.6 | 4.1 | 4.2 | 5.3 | 6.4 | 2.5 | 2.5 |
| Crude fat | 8.8 | 9.3 | 7.9 | 10.2 | 3.7 | 5.7 | 5.3 | 6.7 |
| Crude cellulose | 11.9 | 8.0 | 15.2 | 3.7 | 16.9 | 3.8 | 13.1 | 2.1 |
| NDF | 20.6 | 15.0 | 21.6 | 8.6 | 25.6 | - | 26.0 | 5.8 |
| ADF | 12.9 | 7.8 | 17.4 | 5.4 | 22.2 | 13.6 | 17.2 | 3.2 |

Note: 1 - Laudadio and Tufarelli (2011a); 2 - Písaříková et al. (2008); 3 - Mieczkowska et al. (2005); 4 - King et al. (2000); WS - whole seeds; DS - dehulled seeds; NDF - neutral detergent fibers; ADF - acid detergent fibers.

The fat content can be influenced by the genotype of the species as well as the pedoclimatic growth factors of the plant (Boschin et al., 2008). Rybiński et al. (2018) found a variation of the crude fat content from *L. albus* whole seeds, ranging between 6.9% and 14.1% in DM, with an average of 9.81% DM. According to the data from table 1, by dehulling, the crude fat level increases from 3.7-8.81% of DM (whole seeds) to 5.42-10.23% DM (dehulled seeds).
The high content in crude celullose of lupine seeds slows digestion, affects metabolic assimilation of nutrients and reduces the nutritional value of feed for monogastric animals, incapable to efficiently degrade cellulose. Straková et al. (2006) mention that for the lupine species cultivated in Europe, the content of cellulose in whole seeds varies between 94-142 g/kg and between 124-192 g/kg, values higher than in soybeans. The content of crude celluose in lupine seeds is

about 13% in DM, which is double compared with soybean meal (6.2% DM), peas (5.3% DM) or faba beans (8.1% DM) (Van Barneveld, 1999). Dehulling proces is demonstrated to reduce NDF content by 16% and ADF by 13.7% (Mera-Zuñiga et al., 2018).

The crude ash level in lupin seeds is a good indicator of macroelements and microelements content (Grela et al., 2017). According to table 1, there is a slight increase in ash for dehulled seeds, by a species-dependent mode.

The content in N-free extract (NFE) differs in lupine species and contains, in addition to starch, pectin, more water soluble non-starch polisaccharides and oligosaccharides (Sujak et al., 2006). The content in NFE decreases after dehulling, from 47.8% to 38.3% of DM in kernel (Saez et al., 2015).

The high energy value of lupine seeds is due to high fat content, thus Bartkiene et al. (2016) established the metabolisable energy value to be 369 kcal/100 g for *L. luteus* and 378 kcal/100 g for *L. angustifolius* seeds. The content in non-starch polisaccharides (NSP) depreciates the energy value of lupine seeds for monogastrics animals, demonstrating that for each percentage of NSP presence in lupine seeds administrated to broiler chickens, a decrease with 0.288 MJ of metabolisable energy occurs (Sipsas and Glencross, 2005).

Gross energy suffers minor changes after seeds dehulling, increasing by up 3.4 percentage points for *L. albus* (Saez et al., 2015). King et al (2000) highlight that by dehulling *L. angustifolius* seeds, the digestible energy increases from 15.81 to 16.85 MJ/kg DM. According to Nalle et al. (2010), the $AME_N$ (nitrogen-corrected apparent metabolisable energy) improves with 30% by dehulling the *L. angustifolius* seeds and with 52% according to Mera-Zúñiga et al. (2018).

### *Biological value of lupine seeds protein*

The nutritional value of lupine seed protein is reflected by the essential amino acids content. The value of lupine protein is comparable to the values of soybean meal protein, peas or other legume grains (Sujak et al., 2006). Whole sweet lupine seeds are characterized by a variable amino acid profile, being rich in lysine, leucine, valine, threonine, isoleucine, serine, but deficitary in tryptophan and sulfur amino acids such as methionine and cystine (Table 2). Among the non-essential amino acids, the highest content is in glutamine, aspartic acid and arginine (Nalle et al., 2011).

Table 2. Effect of dehulling on the amino acids content (g/16 g N) of lupine seeds from the low alkaloid varieties

| AA | *L. albus* | | | | *L. luteus* | | *L. angustifolius* | |
|---|---|---|---|---|---|---|---|---|
| | 1* | | 2* | | 3* | 4* | 5* | |
| | WS | DS | WS | DS | WS | DS | WS | DS |
| ***Essential AA*** | | | | | | | | |
| Lys | 3,63 | 3,61 | 5,46 | 5,19 | 5,40 | 3,08 | 4,69 | 4,47 |
| Met | 0,76 | 0,77 | 1,12 | 1,15 | 0,20 | 0,55 | 0,62 | 0,62 |
| Thr | 3,49 | 3,49 | 3,72 | 3,63 | 3,80 | 3,52 | 3,30 | 3,39 |
| Ile | 3,58 | 3,56 | 3,90 | 3,97 | 3,10 | 3,66 | 3,37 | 3,46 |
| Val | 3,69 | 3,70 | 3,74 | 3,70 | 3,30 | 3,41 | 8,22 | 8,77 |
| Leu | 7,24 | 7,24 | 6,26 | 6,17 | 8,20 | 7,80 | 6,09 | 6,22 |
| His | 2,34 | 2,35 | 3,09 | 2,94 | 2,80 | 2,55 | 2,56 | 2,47 |
| Phe | 3,97 | 3,98 | 3,53 | 3,12 | 4,00 | 3,81 | 3,53 | 3,60 |
| ***Non-essential AA*** | | | | | | | | |
| Arg | 9,49 | 9,46 | 11,38 | 11,7 | 11,5 | 11,19 | 8,22 | 8,77 |
| Cys | 1,10 | 1,12 | 2,00 | 2,25 | 2,00 | 7,14 | 9,16 | 9,42 |
| Asp | 10,42 | 10,41 | 10,58 | 10,5 | 11,6 | 10,71 | 3,53 | 3,56 |
| Ser | 5,46 | 5,45 | 5,07 | 5,12 | 6,50 | 5,24 | 3,95 | 4,13 |
| Tyr | 4,08 | 4,08 | 2,39 | 2,13 | 2,30 | 3,08 | 4,31 | 4,37 |
| Glu | 19,92 | 19,89 | 15,10 | 14,7 | 23,7 | 24,63 | 3,92 | 3,96 |
| Pro | 4,17 | 4,17 | 4,18 | 4,20 | 2,30 | 6,63 | 18,45 | 19,7 |
| Gly | 4,31 | 4,31 | 3,79 | 3,76 | 4,50 | 3,96 | 1,29 | 1,20 |
| Ala | 3,41 | 3,42 | 3,20 | 3,17 | 3,60 | 3,37 | 3,82 | 3,82 |

Note: 1 - Laudadio and Tufarelli (2011a); 2 - Písaříková et al. (2008); 3 - Pastor-Cavada et al. (2009); 4 - Smith et al. (2007); 5 - Nalle et al. (2010); * - value adapted at g/16g N; AA - Amino Acids; WS - whole seed; DS - dehulled seed.

As resulting from table 2, the effect of dehulling on the amino acid composition of lupine seeds is a slight improvement in their content. The increase of protein content in amino acids as a result of dehulling depends on species and cultivars (Nalle et al., 2010). According to Mera-Zúñiga et al. (2018), the dehulling process of lupine seeds determines an increase in essential amino acid content by 0.7-0.48 percents. Previously, Písaříková et al. (2009) mention in a review that in dehulled lupine seeds the level of protein and amino acids increases by even 13%. Improving the amino acid content in dehulled seeds also determines the improvement of the biological value of proteins (Straková et al., 2006).

However, given the limited content of lupine seed proteins in some essential amino acids (methionine, tryptophan), this may be used in the nutrition of monogastric animals in association with others plant proteins based on their complementarity and/or by the use of synthetic amino acids (Písaříková et al., 2008).

### **Fatty acids content in lupine seeds**

The fatty acid profile of lupine seeds shows the high content in polyunsaturated fatty acids (especially linoleic and linolenic acids) as well as oleic acid (Table 3), which attributes to lupine seeds the quality for a valuable source of essential fatty acids. Fatty acid content varies with species, cultivars and environmental conditions (Rybiński et al., 2018).

Table 3. Effect of dehulling on the fatty acid content (% of FAME) of lupine seeds from the low alkaloid varieties

| Fatty acids (FA) | *L. albus* | | *L. luteus* | | *L. angustifolius* | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 3 | 4 |
| | WS | DS | WS | WS | WS | WS |
| Palmitic C16:0 | 5.86 | 6.95 | 7.39 | 5.6 | 11.06 | 12.47 |
| Stearic C18:0 | 2.98 | 1.63 | 2.87 | 2.70 | 5.73 | 6.40 |
| Oleic C18:1 n-9 | 47.65 | 57.72 | 22.62 | 24.1 | 36.53 | 34.94 |
| Linoleic C18:2 n-6 | 19.97 | 12.52 | 49.19 | 47.7 | 36.68 | 37.64 |
| Arachidic C20:0 | 0.90 | - | 2.88 | 2.58 | 1.79 | 0.76 |
| α-linolenic C18:3 n-3 | 10.93 | 7.89 | 7.98 | 6.86 | 4.32 | 4.53 |
| Behenic C22:0 | 3.15 | - | - | 5.61 | - | 1.40 |
| Gadoleic C20:1 n-9 | 6.82 | - | 1.88 | 1.55 | 0.34 | 0.23 |
| Erucic C22:1 n-9 | 1.42 | - | 0.61 | 0.70 | 0.17 | 0.03 |
| Σ SFA | 12.89 | 9.96 | 5.80 | 17.5 | 11.10 | 21.78 |
| Σ MUFA | 56.21 | 65.54 | 13.3 | 26.4 | 23.70 | 35.26 |
| Σ PUFA | 30.90 | 24.50 | 30.70 | 55.2 | 27.40 | 42.3 |
| n-3/n-6 FA | 0.55 | 1.10 | - | 7.12 | - | 8.34 |

Note: 1 - Mierlita et al. (2018); 2 - Volek et al. (2018); 3 - Grela et al. 2017; 4 - Andrzejewska et al. (2016); SFA - saturated fatty acids; MUFA - monounsaturated fatty acids; PUFA - polyunsaturated fatty acids; FAME - mettyl esterified fatty acids; n-3/n-6 = linolenic/linoleic fatty acids; WS - whole seed; DS - dehulled seed.

The nutritional value of lipids is represented by the content and profile of fatty acids as well as by their report. In *L. angustifolius* and *L. luteus* whole seeds, linoleic acid has the highest level, followed by oleic acid, but oleic acid followed by linoleic have the highest level in *L. albus* (Boschin et al., 2008; Andrzejewska et al., 2016). According to Chiofalo et al. (2012), the high content in gadoleic and oleic acid is specific for *L. albus*.

As shown in the table 3, monounsaturated fatty acids (MUFAs) are well represented in whole seeds of *L. albus* (56.21%) and polyunsaturated acids (PUFAs) in whole seeds of *L. luteus* and *L. angustifolius* (27.4% - 55.24%). According to Musco et al (2017) white lupine is representative for the high MUFA content (54.4% of FAME), yellow lupine is for PUFA (56.9% of FAME) and blue lupine is for SFA (24.8% of FAME). Polyunsaturated fatty acids are essential nutrients and the linolenic/linoleic ratio (ω-3/ω-6) is important for animal nutrition (Suchy et al., 2008).

Uzun et al. (2007) found that the high proportion of oleic fatty acid (47.6% of FAME) from whole white lupin seeds is negatively correlated with linoleic fatty acid (20.3% of FAME) and the latter was positively correlated with the fat content of the seeds.

Dehulling lupine seeds contributes to a slight improvement of some fatty acid levels and table 3 reveald that the MUFA content (65.54% of FAME) is high in dehulled *L. albus* seeds. The eicosenoic acid level in *L. albus* dehulled seeds is 5.21% of FAME and palmitoleic acid represents 0.35% of FAME (Volek et al., 2018). According to Suchy et al. (2008), after dehulling, the content of fatty acids presents an increase with 20.04-25.18% in *L. albus*, *L. luteus*, *L. angustifolius* dehulled seeds.

**Content in minerals and vitamins of lupine seed**

The vitamin and mineral content in low-alkaloid lupine seeds is significantly influenced by species and cultivars (Bartkiene et al., 2016; Karnpanit et al., 2017). Lupine seeds are characterized by an appreciable content in minerals such as Ca, P and K (Table 4).

Table 4. The content of minerals in whole lupine seeds (g/kg DM) from the low alkaloid varieties

| Minerals | *L. albus* | | *L. luteus* | | *L. angustifolius* | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 1 | 3 | 1 | 3 |
| Ca | 3.6 | 2.38 | 3.3 | 2.95 | 3.4 | 3.33 |
| K | 11.9 | 11.0 | 12.8 | 12.6 | 11.0 | 13.4 |
| P | 4.8 | 5.23 | 8.1 | 7.47 | 4.9 | 6.84 |
| Mg | 1.9 | 1.35 | 3.1 | 3.14 | 2.0 | 2.10 |
| Na | 0.118 | 0.17 | 0.096 | 0.08 | 0.094 | 0.08 |
| Fe | 0.059 | 0.038 | 0.095 | 0.13 | 0.061 | 0.07 |
| Mn | 0.672 | 0.252 | 0.065 | 0.08 | 0.041 | 0.13 |
| Zn | 0.047 | 0.043 | 0.077 | 0.070 | 0.0391 | 0.070 |
| Cu | 0.0061 | 0.0082 | 0.010 | 0.020 | 0.0046 | 0.040 |

Note: 1 - Wasilewko (1999); 2 - Grela et al. (2017); 3 - Rutkowski et al. (2015).

According to Grela et al. (2017), P and K are well represented in *L. angustifolius* and *L. luteus*; Ca is found in higher quantities in *L. albus* and the high content in Mg is characteristic for *L. luteus*.

Phytic acid is the main factor that reduces the bioavailability of minerals in leguminous grains, because it is bound in non-degradable phytates due to chelation with Cu, Fe, Zn, Ca, Mg, K cations (Gupta et al., 2015). The phytic acid content of whole lupine seeds (~ 1%) reduces the bioavailability of phosphorus (Kasprowicz et al., 2016). For *L. angustifolius*, it has been demonstrated that the dehulling of seeds produces a reduction in total phosphorus from 3.5 to 1.0 g/kg DM (Kim et al., 2012).

Beacause of the hulls store the most Ca, the dehulling process of lupine leads to a decrease from 0.36 % to 0.24 % of DM, but the level in P increases from 0.61% to 0.77% of DM (Mera-Zúñiga et al., 2018) due to its presence in the kernel (Večerek et al., 2008 ). Karnpanit et al. (2017) highlight that although the level of Ca decrease in *L. angustifolius* seeds by dehulling, its bioavailability increases from 6.0 to 10.5 %.

The content in vitamins of whole *L. albus* seeds is 3.9 mg/kg DM for thiamine, 2.3 mg/kg DM for riboflavin and 39.1 mg/kg DM for niacin (Erbaş et al., 2005). The niacin level of lupine seeds is higher compared with that of soybean meal (32.6 mg/kg DM) (Erbaş et al., 2005). Martínez-Villaluenga et al. (2006) show for *L. albus* and *L. luteus* a vitamin E content between 0.19-0.47 mg/100 g DM, a vitamin C content of 2.56-6.48 mg/100 g DM and a riboflavin content of 0.37-0.85 mg/100 g DM.

## RESULTS AND DISCUSSIONS

## ANTINUTRITIONAL FACTORS OF LUPINE SEEDS FROM LOW-ALKALOID VARIETIES

New varieties of sweet lupine seeds are characterized by a low content of alkaloids (less than 0.02%), but there are certain antinutritional factors such as cellulose (NDF and ADF), non-starch polysaccharides and oligosaccharides that reduce the value of nutrients from lupine seeds, especially for monogastric animals (Musco et al., 2017). These compounds cannot be degraded by the endogenous enzymes of monogastrics due to the absence of specific enzymes.

### Non-starch polysaccharides (NSP)

Lupine seeds are characterized by a significant content in antinutritional substances such as non-starch polysaccharides, bioactive compounds that cannot be efficiently metabolized by endogenous enzymes of monogastric animals (Smulikowska et al., 2014; Hejdysz et al., 2018b). In poultry nutrition, NSP have a low digestibility and reduce the efficiency of feed utilization, representing the most important antinutritive factor from lupine seeds (Kaczmarek et al., 2016b). Their content in whole seeds is up to 40% of DM (Petterson, 2000).

Lupine seeds contain 22-24% hulls and 76-78% kernel (Van Barneveld, 1997; Večerek et al., 2008). Polysaccharides such as cellulose, hemicellulose, arabinoxylans and pectins are found in the structure of the hull, and carbohydrates such as non-structural cell wall polysaccharides (arabinose, galactose, uronic acid) are found in the kernel (Table 5). The most important cell wall polysaccharide is cellulose (48.1% of DM, in hulls) (Knudsen, 2014), amounting in whole lupine seeds to 167-192 g/kg DM (Gdala and Buraczewska, 1996).

Table 5. Effect of dehulling on the non-starch polysaccharide content (g/kg DM) of lupine seeds

| PNA | *L. albus* | | *L. luteus* | | *L. angustifolius* | |
|---|---|---|---|---|---|---|
| | 1 | 1 | 2 | 3 | 1 | 1 |
| | WS | DS | WS | WS | WS | DS |
| Rhamnose | 2.4 | 1.0 | 1.1 | - | 2.8 | 1.2 |
| Arabinose | 44.9 | 38.1 | 34.8 | 39.4 | 45.7 | 43.9 |
| Xylose | 37.6 | 17.5 | 26.3 | 34.9 | 27.9 | 22.3 |
| Mannose | 15.2 | 9.1 | 3.5 | 4.5 | 16.0 | 12.5 |
| Galactose | 154.4 | 142.6 | 52.2 | 58.2 | 190.1 | 191.8 |
| Glucose | 95.6 | 36.0 | 85.0 | 126 | 115.8 | 47.4 |
| Total PNA | - | - | 240.2 | 302.2 | - | - |

Note: 1 - King et al. (2000); 2 - Olkowski (2011); 3 - Krawczyk et al. (2015b); PNA - non-starch polysaccharides; WS - whole seed; DS - dehulled seed.

In kernel of lupine seeds there are some fractions of soluble NSP and oligosaccharides that favor fermentation processes in the small intestine, thus reducing the efficiency utilisation of feed energy from monogastric animal diets (King et al., 2000, Lee et al., 2016). The soluble fraction is considered to have an antinutritional effect characterized by increasing the intestinal passage time and gives a viscosity consistency to the digesta (Konieczka and Smulikowska, 2017). The content of lupine in soluble NSP is 5-10% (Evans et al., 1993; Kocher et al., 2000). Insoluble fractions (approximately 30%) do not have major negative effects on the utilisation of

nutrients by monogastric animals, with even positive effects on intestinal motility (Petterson, 2016).
According to the results reported by King et al. (2000), the dehulling process reduces the content of NSP from lupine seeds (Table 5). Nalle et al. (2010) found that, by dehulling, a reduction in the content of *L. angustifolius* seeds in soluble NSP (from 31.5 to 19.3 g/kg) and insoluble (from 463 to 240 g/kg) is produced. For poultry, NSP lead to an increase of intestinal digesta viscosity (especially in the ileum) and excretion humidity, reducing the ingestion and the degree of feed utilization and on the other hand, alters the microclimate parameters of poultry breeding shelters (Kocher et al., 2000; Steenfeldt et al., 2003).

**Raffinose family oligosaccharides (RFO)**

The main oligosaccharides present in lupine are raffinose, stachyose, verbascose and sucrose (Table 6). The content in seeds differs according to species, varieties and year of cultivation (Karnpanit et al., 2016).
Oligosaccharides are found in high proportions in lupine seeds, presenting variations between 5.3-12.3% of DM, and *L. luteus* is the species with highest content of oligosaccharides (9.46-12.3% DM) (Martínez-Villaluenga et al., 2005). According to Stanek et al (2015), the oligosaccharide content in *L. angustifolius* varies between 63.2 and 73.6 g/kg DM.

Table 6. The raffinose family oligosaccharides content (g/kg DM) of lupine seeds from low alkaloid varieties

| RFO | *L. albus* | | *L. luteus* | | *L. angustifolius* | |
|---|---|---|---|---|---|---|
| | WS 1 | DS 1 | WS 2 | WS 3 | WS 4 | WS 5 |
| Saccharose | 24.9 | 26.3 | 19.68 | - | - | - |
| Raffinose | 7.02 | 7.92 | 10.91 | 11.0 | 12.0 | 13.0 |
| Stachylose | 43.4 | 59.1 | 74.15 | 49.4 | 56.1 | 53.0 |
| Verbascose | 7.47 | 10.3 | 45.85 | 25.3 | 19.6 | 19.0 |
| Total RFO | 83.5 | 104.3 | 130.91 | 85.7 | 87.7 | 85.0 |

Note: 1 - Písaříková et al. (2008); 2 - Chilomer et al. (2012); 3 - Rutkowski et al. (2016); 4 - Hejdysz et al. (2018a); 5 - Karnpanit et al. (2016). RFO - raffinose family oligosaccharides; WS - whole seed; DS - dehulled seed.

According to the values from Table 6, there is no positive change in the content of oligosaccharides by dehulling lupine seeds. An increase of their level is observable, but it may be due to the method of dehulling (wet or dry method) (Karnpanit et al., 2016). According to Brenes et al. (2003), the *L. albus* dehulled seeds have a higher content in total RFO than whole seeds: 63.4 mg/g vs. 58.8 mg/g. Lupine whole seeds contain more oligosaccharides (8.26%) than soybean seeds (6.96%), sunflower (1.73%) or rape (1.79%) (Geigerová et al., 2017).

**Alkaloid content**

Currently, sweet lupine varieties of *L. luteus*, *L. albus* and *L. angustifolius* species with low-alkaloids content are cultivated (Frick et al., 2017). Therefore, the inconvenience generated by the presence of a high level of alkaloids has been eliminated, which has led to the progressive use of lupine in animal feeds.
However, the content of alkaloids in lupine seeds is influenced by some factors such as species, cultivars, geographical area or pedo-climatic conditions (Güémes-Vera et al., 2012; Maknickiene et al., 2013; Romeo et al., 2018). In the whole seeds of *L. albus*, the total alkaloid content ranges from 3.63 to 165 mg/100 g (Calabrò et al., 2015). In *L. luteus* the level of alkaloids is 42.6-58.5 mg/kg (Kaczmarek et al., 2016b) and in *L. angustfolius* it is 0.36-0.56 mg/kg (Stanek et al., 2015). The main alkaloids from lupine seeds are lupanine (34.6 mg/100 g in *L. albus*), sparteine (1.01 mg/100 g in *L. luteus* and 1.24 mg/100 g in *L. angustifolius*), angustifoline (1.28 mg/100 g in *L. albus* and 0.45 mg/100 g in *L. angustifolius*), 13-α-hydroxylupanine (2.54 mg/100 g in *L. albus* and 1.34 mg/100 g in *L. angustifolius*) (Musco et al., 2017).

## THE UTILIZATION OF SWEET LUPINE SEEDS IN THE MONOGASTRIC ANIMAL FEEDING

**Use of lupine seeds in poultry feeding**

Attempts to use lupine seeds as the main source of protein in poultry feeding are an objective of researches in the field. Poultry have the ability to efficiently use the amino acids and energy of lupine, but the antinutritive factors minimize their biological potential to valorize their nutrients. Studies are primarily focused to determine the bioproductive effects of lupine as a result of the substitution of protein from soybean meal in different proportions. Soybean meal is the most important protein source in poultry feeding.

*Use of lupine seeds in broiler chicken feeding*

Raw lupine seeds can be administered to broiler chicken feed in a proportion of 15% to 25, without exerting negative effects on bioproductive performances (Brenes et al., 2002; Hejdysz et al., 2018b). According to some studies conducted by Straková et al. (2010), the administration of 8.67 to 31.03% lupine seeds in broiler chicken (1-42 days) feeds has been shown to improve the quality of breast and thigh muscles, with an increase in the MUFA content of lipids, especially in oleic acid ($p < 0.01$), compared to chickens that had soybean meal in their diet. Authors conclude that the inclusion of lupine in broiler feeding increases the nutritional value of the meat.

Most of studies show that the use of lupine in broiler chicken feeding over the tolerance limit of the organism mainly affects the bioproductive performance and physiological status. In this respect, Brenes et al. (2002) highlight that the inclusion of lupine (*L. albus*) in 35% and 45% in broiler diet at the whole growing period, determines the depreciation of growth performances compared to the group in which soybean meal was added. Kaczmarek et al. (2016a) observed that the inclusion of yellow lupine meal over 150 g/kg in diets of 1-35 days old chickens negatively affects growth performances (body weight gain, feed consumption) compared to the control group (whith soybean meal) and causes a linear decrease of $AME_N$ and ileal digestibility of protein, fat and starch from the diet. The use of whole blue lupine seeds in quantities up to 250 g/kg combined fodder, leads to an increase in the ileal viscosity directly proportional with the dose of lupine inclusion, for 1-35 days old broiler chickens (Hejdysz et al., 2018c). Also, Smulikowska et al (2014) observed that the inclusion of 25% *L. angustifolius* seeds in combined fodder for 36 days old broiler chickens, determines a significant increase of the ileal viscosity.

In order to diminish the effects caused by the antinutritive factors, it has been shown that some methods such as dehulling the seeds and/or supplementation of feed with specific enzymes increase the organism tolerance and the bioproductive efficiency of lupine (Annison et al., 1996; Orda et al., 2006). The use of dehulled lupine seeds in broiler feeds has been shown to reduce the negative effects of antinutritive substances (Guillamón et al., 2008; Nalle et al., 2010). Brenes et al. (2003) found an improvement with 68 percent for oligosaccharides ileal digestibility in the case of *L. albus* dehulled seed usage in the diet of broiler chickens with the age of 14-18 days, compared to the use of whole seeds. Both dehulling and enzyme addition in the combined feed significantly improved ($p<0.05$) the weight gain of chickens, feed conversion and protein digestibility. Mieczkowska et al. (2005) observed that after dehulling lupine seeds, the ileal viscosity of chickens decreased with 37%.

Diaz et al. (2006) found that the administration of 300 g/kg of dehulled lupine in broiler chicken diets significantly reduced ($p<0.01$) feed consumption throughout the growing period compared to the similar amount in whole form, and to the administration of soybean meal in the control group.

Laudadio and Tufarelli (2011a) established the reduction in fat deposition ($p<0.05$) and the increase of water-holding capacity in breast and drumstick meat (juiciness indicator) for 14-49 days of broiler growing period, in which the feed incorpored dehulled *L. albus* seeds (240 g/kg). Compared to the control group where soybean meal was administered (195 g/kg), the dehulling of lupine did not modify the dressing percentage, or the breast and drumstick percentages.

According to Mera-Zúñiga et al. (2018), the total substitution of soybean meal from broiler feed with *L. angustifolius* dehulled seeds, throughout the whole growing period, can generate a similar weight gain and even a better feed conversion ($p < 0.05$) if the specific enzymes are used in the feed compound.

*Use of lupine seeds in laying hens feeding*

Numerous studies reveal the bioproductive effects resulted by the different inclusions of lupine seeds in the feed compound of laying hens, highlighting the possibility of improving the degree of seed utilization by applying a subsequent initial physic and/or enzymatic treatment to inactivate or eliminate the major antinutritional factors.

Studies show that whole lupine can be admitted in the laying hens diet up to 20% (Lee et al.,

2016) or even 25% (in feed) if combined fodder is supplemented with methionine (amino acid deficitary in lupine) (Hammershøj and Steenfeldt, 2005). The results obtained by Drażbo et al. (2014) indicate that whole seeds of *L. angustifolius* can be introduced up to 20% in the feed of laying hens in the 18-38 weeks period without affecting the egg production. These authors show that, regarding the quality of eggs, a substitution with 10-20% of soybean meal with whole blue lupine seeds contributes to an increase in C18:3 n-3 and C18:2 n-6 acids and total polyunsaturated fatty acids from the yolk lipids, improving the PUFA n-6/n-3 ratio. Regarding the physical properties of the eggs, the authors report a significant increase in the shell weight and the breaking strength.

Krawczyk et al. (2015a) observed an improvement in PUFA from yolk lipids as well as certain sensory parameters (intensified yolk color) when yellow lupine flour (whole seeds) was added up to 30% in feed compound of laying hens of 32-48 weeks age. Authors demonstrate that the bioproductive performances (feed consumption, feed conversion rate, eggs production, egg weight) and the characteristics of egg components (thickness and strength of the shell, relative weight of yolk, the quality of the egg expressed as Haugh units) are not affected. Park et al (2016) conclude that supplementing the dites based on soybean meal with blue lupine (whole seeds) up to 22% can improve the egg production of hens ($p<0.05$) without affecting daily feed intake .

Zduńczyk et al (2014a) report that 20% blue lupin meal (whole seeds) used in the laying hens feed (18-42 weeks growing period) exercite positive effects on the majority of microbiota from the caecum, consisiting in the significant increases of beneficial bacteria from the genera *Bifidobacterium*, *Lactobacillus* or *Enterococcus* and a decrease in the number of potential pathogenens such as *E. coli*, *Prevotella*, *Bacteroides* and *Porphyromonas*, compared to the hens fed with soybean meal. In addition, there was a significant contribution of lupine in the increases of cecal microbiota enzyme activities such as α-arabinopyranosidase, α- and β-glucosidase, α- and β-galactosidase.

Research conducted by Laudadio and Tufarelli (2011b) indicates that dehulled and micronised lupines (*L. albus*) represent a suitable ingredient for laying hens production (18-28 weeks) and the complete replacement of soybean meal (150 g/kg) with lupine (180 g/kg) in the combined fodder produced similar bioproductive performances.

*Use of lupine seeds in feeding other species of poultry*

Usage of whole *L. luteus* (Zduńczyk et al., 2014b) and *L. angustifolius* (Mikulski et al., 2014) seeds in the feeding of turkeys (aged 13 to 18 weeks) as a protein substitute for soybean meal in proportions up to 18%, has been shown to not affect negatively the bioproductive performances, carcass properties or sensorial indices of the meat.

In feeding of turkeys in the first 4 weeks of growth, lupine meal (from whole seeds) may be included up to 16% without affecting the bioproductive performances, and in the following growth phases it may be included in the diet up to 24%, thus successfully substituting soybean meal (Krawczyk et al., 2015b). The authors point out that the presence of lupine in compound feed has led to a significant decrease in the concentration of saturated fatty acids from lipids. Compared to the control group (with soybean meal), in groups where lupin seeds was utilized up to 24%, a significant increase ($p<0.001$) of polyunsaturated fatty acids in lipids, including linoleic acid and linolenic acid was found, without altering the PUFA n-6/n-3 ratio, but improving the value of the atherogenic and thrombogenic indices.

In the feeding of 1 to 40 days-old ducks, substitution of soybean meal with *L. albus* whole seeds in a 50% proportion in the diet has not been shown to significantly improve the live weight of the ducks, but has increased the content of Lactobacilli and Bifidobacteria from the caecum ($p <0.05$) (Geigerová et al., 2017).

In the Japanese quail diets for 1 to 42 days-old, the usage of 15% white lupine seeds in combined fodder proved to be more effective in dehulled form than whole, but compared to the group that benefited of soybean meal as a protein source in the diet, the bioproductive effects of lupine were insignificant (Arslan and Seker, 2002).

**Use of lupine seeds in swine feeding**

Data from the scientific literature on the optimal inclusion and efficiency of using lupine seeds in the diets of swine are characterized by controversial results of bioproductive effects.

In the feeding of young pigs (10-20 kg) lupine is recommended to be used with caution due to the incomplete development of thier digestive system (McNiven and Casteli, 1995). According to Kim et al. (2011), the optimum inclusion level of whole lupine seeds (*L. angustifolius*) in the diet of growing pigs is 5 - 10% to weaners, 20% to growers and up to 35% in the fattening period. The presence of white lupine in the swine feed is associated with changes in the fatty acid structure of intramuscular and storage fat, so the major fatty acid in white lupine (oleic acid) was found in significant amounts in the intramuscular and storage fats, together with the linoleic and linolenic acid (Petterson et al., 2000).

Froidmont et al. (2005) suggest that α-galactosides are the main antinutritive factor in lupine seeds for the growth and finishing phase of the swine, due to the binding of nutrients in non-digestible complexes. Also, α-galactosides cannot be efficiently degraded in the small intestine of pigs due to an α-galactosidase deficiency (Gdala et al., 1997).

Kasprowicz et al. (2016) mention that whole seeds of *L. angustifolius* may partly replace soybean meal in feeds for starter, growth and fattening (20 - 105 kg body weight) phases, without affecting the bioproductive parameters, noting that in the starter phase better results are obtained by substituting soybean meal with 20% lupine. Also, Zralý et al. (2007) mention that soybean meal can be completely replaced with lupine (whole) in diets for fattening pigs with the condition of equilibration the ratio in essential amino acids such as methionine, according to the requirements of the category.

Dehulled white lupine seeds may substitute partially or totally (100%) soybean meal in the starter, growth and finishing phases without significantly affecting the bioproductive performances or nutritional parameters of the meat (Zralý et al., 2008).

Písaříková et al. (2008) mention that by a complete replacement of protein from soybean meal in the basal diet of growing pigs with protein from dehulled white lupin, similar bioproductive performances can be obtained. Also, compared to the control group, the digestibilities of organic matter ($p<0.01$), crude protein ($p<0.05$), crude fat and crude cellulose ($p<0.01$), N-free extract ($p<0.01$) NDF, ADF and cellulose ($p<0.01$) are increasing. In addition, the authors report that the digestibility of threonine ($p<0.01$) and lysine was higher, whereas for methionine it was lower.

According to Prandini et al. (2010), *L. albus* dehulled seeds can be included in weaned piglet (28 - 70 days) diets in a dose of 170 g/kg without significantly affecting the growth performances (body weight gain, feed consumtion and feed conversion index) compared with piglets fed with soybean meal. Kim et al. (2012) report the possibility of using *L. angustifolius* dehulled seeds as a substitute for whey and skim milk powder in weaner pigs, because similar growth performances are achieved up to a replacement of 75% (180 g/kg) lupine in the diet.

## CONCLUSIONS

In conclusion, the lupine species from low-alkaloid varieties represent a promising alternative source of protein to soybean meal protein in monogastric animal nutrition. Studies highlight that the process of seed dehulling significantly improves the nutritional value of lupine. Researches on the bioproductive efficiency of whole lupine seeds in poultry and swine feeding highlight the possibility of inclusion of lupine seeds in limited proportions in the combined fodder, as soybean meal replacement. Seed dehulling is a method that greatly improves the bioproductive efficiency of lupine utilisation in monogastric animals, increasing the organism tolerance. Thus, depending on the species, age category and direction of exploitation, the dehulled lupine seeds can substitute in larger proportions the soybean meal from the feed, with the condition of balancing the ration in deficient amino acids.

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